

**METHODS FOR FORMING A PERMEABLE AND STABLE MASS IN A
SUBTERRANEAN FORMATION**

1. Field of the Invention.

[001] The present invention provides methods for creating a permeable and stable mass. More particularly, the present invention relates to increasing the permeability of a subterranean formation by forming a resinous mass having conductive channels through which fluids can be produced in the formation.

2. Description of the Prior Art.

[002] To enhance the permeability of a formation, it is often desirable to create a stable mass having conductive channels through which fluids can flow within the formation. For example, a subterranean formation may be treated to increase its permeability by hydraulically fracturing the formation to create or enhance one or more cracks or "fractures." Such hydraulic fracturing is often accomplished by injecting a viscous fracturing fluid at a rate and pressure sufficient to cause the formation to break down and produce one or more fractures. The fracture or fractures may be horizontal or vertical, with the latter usually predominating, and with the tendency toward vertical fractures increasing with the depth of the formation being fractured. Proppant may then be deposited in the fracture to form a proppant pack once the hydraulic pressure is released. The proppant pack functions as a stable mass, *inter alia*, to hold the fracture open while maintaining conductive channels through which such produced fluids can flow upon completion of the fracturing treatment.

[003] Another situation in which it is desirable to create a stable mass having conductive channels is in a sand control operation. Sand control operations are used to reduce the migration of unconsolidated formation particulates. One common type of gravel packing operation involves placing a gravel pack screen in the well bore and packing the surrounding annulus between the screen and the well bore with gravel of a specific size designed to prevent the passage of formation sand. The gravel pack screen is generally a filter assembly used to retain the gravel placed during gravel pack

operation. A wide range of sizes and screen configurations are available to suit the characteristics of the gravel pack sand used. Similarly, a wide range of sizes of gravel is available to suit the characteristics of the unconsolidated or poorly consolidated particulates in the subterranean formation. The resulting structure presents a barrier to migrating sand from the formation while still permitting fluid flow. When installing the gravel pack, the gravel is carried to the formation in the form of a slurry by mixing the gravel with a transport fluid. Gravel packs act, *inter alia*, to stabilize the formation while causing minimal impairment to well productivity. The gravel, *inter alia*, acts to prevent the particulates from occluding the screen or migrating with the produced fluids, and the screen, *inter alia*, acts to prevent the gravel from entering the production tubing.

[004] Traditionally, operations that form stable, conductive masses, such as the fracturing and sand control operations described above, use viscous servicing fluids to deliver the particulates. Once those operations are complete, the servicing fluids must generally be removed from the well bore and/or the subterranean formation. To accomplish that goal, the viscous servicing fluid may be “broken,” that is, its viscosity reduced to make it easier to displace the fluid from the well bore or formation. The recovery of such servicing fluids is time consuming and may result in less desirable production due to polymer residue that remains in the formation.

SUMMARY OF THE INVENTION

[005] The present invention provides methods for creating a permeable and stable mass. More particularly, the present invention relates to increasing the permeability of a subterranean formation by forming a resinous mass having conductive channels through which fluids can be produced in the formation.

[006] Some embodiments of the present invention provide methods of creating a permeable resinous mass comprising the steps of selecting an interval along a well bore; providing a resin slurry comprising an acid curable resin, filler, and degradable material; placing the resin slurry into the selected interval; and, activating the acid curable resin using an activator wherein the activation causes the acid curable resin to substantially cure, the degradable material to substantially degrade, and forms the permeable resinous mass.

[007] Other embodiments of the present invention provide methods of producing hydrocarbons through a permeable resinous mass comprising the steps of selecting an interval along a well bore in a producing subterranean formation; providing a resin slurry comprising an acid curable resin, filler, and degradable material; placing the resin slurry into the selected interval; and, activating the acid curable resin using an activator wherein the activation causes the acid curable resin to substantially cure, the degradable material to substantially degrade, and forms the permeable resinous mass; producing hydrocarbons from the subterranean formation through the permeable resinous mass.

[008] Other and further objects, features and advantages of the present invention will be readily apparent to those skilled in the art upon a reading of the description of preferred embodiments which follows.

DESCRIPTION OF PREFERRED EMBODIMENTS

[009] The present invention provides methods for creating a permeable and stable mass. More particularly, the present invention relates to increasing the permeability of a subterranean formation by forming a resinous mass having conductive channels through which fluids can be produced in the formation.

[010] In some embodiments of the present invention an acid curable resin slurry comprising acid curable resin, filler, and solid degradable material is placed in an isolated interval of a well bore and activated. The activation, *inter alia*, causes the resin to become substantially solid and causes the solid degradable material to become a liquid or gas; thus leaving behind a network of conductive channels in the remaining, substantially solid, mass of resin and filler.

[011] One skilled in the art will be aware of numerous methods for isolating a zone of interest along a subterranean well bore. The isolated interval may be a section of the well bore, a section of the formation surrounding the well bore, or a combination of the two. In some embodiments of the present invention, the isolated interval is a section of producing formation that is to be fractured.

[012] Acid curable resins suitable for use in the resin slurries of the present invention include, but are not limited to, furan-based resins, phenolic-based resins, and phenol/phenol formaldehyde/furfuryl alcohol resins. Generally, the resin component of the resin slurry will make up from about 3% to about 70% by weight of the total resin slurry.

[013] Selection of a suitable resin may be affected by the temperature of the subterranean formation to which the fluid will be introduced. By way of example, for subterranean formations having a bottom hole static temperature ("BHST") ranging from about 60°F to about 600°F, a furan-based resin may be preferred. For subterranean formations having a BHST ranging from about 200°F to about 400°F a phenolic-based resin may be suitable. For subterranean formations having a BHST of at least about 175°F, a phenol/phenol formaldehyde/furfuryl alcohol resin also may be suitable.

[014] One acid curable resin suitable for use in the methods of the present invention is a furan-based resin. Suitable furan-based resins include, but are not limited to, furfuryl alcohol resins, mixtures furfuryl alcohol resins and aldehydes, and a mixture

of furan resins and phenolic resins. Of these, furfuryl alcohol resins are preferred. A furan-based resin may be combined with a solvent to control viscosity if desired. Suitable solvents for use in the furan-based consolidation fluids of the present invention include, but are not limited to 2-butoxy ethanol, butyl lactate, butyl acetate, tetrahydrofurfuryl methacrylate, tetrahydrofurfuryl acrylate, esters of oxalic, maleic and succinic acids, furfuryl acetate, and combinations thereof.

[015] Another resin suitable for use in the methods of the present invention is a phenolic-based resin. Suitable phenolic-based resins include, but are not limited to, terpolymers of phenol, phenolic formaldehyde resins, and a mixture of phenolic and furan resins. Of these, a mixture of phenolic and furan resins is preferred. A phenolic-based resin may be combined with a solvent to control viscosity if desired. Suitable solvents for use in the phenolic-based consolidation fluids of the present invention include, but are not limited to butyl acetate, butyl lactate, furfuryl acetate, 2-butoxy ethanol, and combinations thereof.

[016] Yet another resin suitable for use in the methods of the present invention is a phenol/phenol formaldehyde/furfuryl alcohol resin comprising from about 5% to about 30% phenol, from about 40% to about 70% phenol formaldehyde, and from about 10 to about 40% furfuryl alcohol.

[017] A silane coupling agent may be used with the resins of the present invention, *inter alia*, to act as a mediator to help bond the resin to the filler surface when the resin slurry is formed. Examples of silane coupling agents that can be used in the present invention include, but are not limited to, n-2-(aminoethyl)-3-aminopropyltrimethoxysilane, 3-glycidoxypropyltrimethoxysilane, and n-beta-(aminoethyl)-gamma-aminopropyl trimethoxysilane. Of these, n-beta-(aminoethyl)-gamma-aminopropyl trimethoxysilane is preferred. When used, the silane coupling agent is added in an amount capable of sufficiently bonding the resin to the filler material. In one embodiment of the present invention, the amount of silane coupling agent used ranges from about 0.1% to about 3% by weight of the resin in the resin slurry.

[018] A surfactant also may be used with the resins of the present invention so long as the surfactant is compatible with chosen resin and the subterranean formation. Suitable surfactants include, but are not limited to, ethoxylated nonyl phenol phosphate

esters, mixtures of one or more cationic surfactants, and one or more non-ionic surfactants and alkyl phosphonate surfactants. The surfactant or surfactants used may be included in an amount in the range of from about 2% to about 15% by weight of the resin.

[019] Fillers suitable for use in the resin slurries of the present invention are those materials that are relatively inexpensive and that will not combust or degrade when the resin slurry is activated. Suitable such fillers include but are not limited to, sand, particulates such as proppant or gravel, ground walnut hulls, polymer particles, microspheres, glass particles, ceramic particles, silica particles, carbon black powder, rubber particles such as from ground tires, combinations thereof, and the like. The filler may be used to add relatively low-cost volume to the resin slurry. Generally, the resin component of the resin slurry will be a relatively expensive portion of the treatment of the present invention. By placing filler in the resin slurry, the total volume of the final slurry can be increased at a minimal expense. If the chosen filler has a high strength, its addition to the resin slurry also may improve the strength of the final cured mass. Generally, the filler component of the resin slurry will make up from about 5% to about 50% by weight of the total resin slurry.

[020] Degradable materials suitable for use in the resin slurries of the present invention include, but are not limited to, degradable polymers, dehydrated salts, and mixtures of the two. Generally, the degradable material component of the resin slurry is included in the resin composition in an amount sufficient to create a substantial number of conductive channels through the resin mass. In some embodiments of the present invention, the degradable material component will make up from about 1% to about 50% by weight of the total resin slurry. The amount of the degradable material in the resin slurry should not be such that when degraded, an undesirably high percentage of voids are left in the resinous mass. Too many voids may render the mass potentially ineffective in providing a sand control means. One of ordinary skill in the art, with the benefit of this disclosure, will recognize an optimum concentration of degradable material that provides desirable enhanced permeability and sand control.

[021] Polymers suitable for use as a degradable material of the present invention may be considered degradable if the degradation is due, *inter alia*, to chemical and/or

radical process such as hydrolysis, oxidation, or enzymatic decomposition. The degradability of a polymer depends at least in part on its backbone structure, type of repetitive unit, composition, sequence, length, molecular geometry, molecular weight, morphology (*e.g.*, crystallinity, size of spherulites, and orientation), hydrophilicity, hydrophobicity, surface area, and additives. Also, the environment to which the polymer is subjected may affect how it degrades, *e.g.*, temperature, presence of moisture, oxygen, microorganisms, enzymes, pH, and the like.

[022] Examples of suitable degradable materials include, but are not limited to, substantially water insoluble esters such as ortho esters; poly(orthoesters); aliphatic polyesters; lactides, poly(lactides); glycolides; poly(glycolides); poly(ϵ -caprolactone); poly(hydroxybutyrates); anhydrides; poly(anhydrides); poly(amino acids); polysaccharides such as dextran or cellulose; chitins; chitosans; proteins; aliphatic polycarbonates; poly(ethylene oxides); polyphosphazenes; particulate solid anhydrous borate materials such as anhydrous sodium tetraborates (also known as anhydrous borax) and anhydrous boric acid.

[023] Blends of degradable materials also may be suitable. One example of a suitable blend of materials includes a blend of a poly(lactic acid) and an ortho ester. Other materials that undergo degradation and produce acid also may be suitable, if the products of the degradation do not undesirably interfere with either the subterranean treatment being performed or the subterranean formation.

[024] The specific features of the degradable material may be modified to provide the resin mass with optimum permeability while maintaining its desirable functionality. For instance, the degradable material may be selected to have a size and shape to maintain a substantial uniformity within the mixture. The degradable materials may have any shape, including but not limited to particles having the physical shape of platelets, shavings, flakes, ribbons, rods, strips, spheroids, toroids, pellets, tablets, or any other physical shape. The physical shape of the degradable material should be chosen so as to enhance the desired shape and relative composition of the resultant voids within the mass. In certain preferred embodiments, a degradable material having a rod-like particle shape is used to create interconnecting channel-like voids in the permeable cement mass.

One of ordinary skill in the art with the benefit of this disclosure will recognize the specific degradable material and the preferred size and shape for a given application.

[025] In choosing the appropriate degradable material, one should consider the degradation products that will result. Also, these degradation products should not adversely affect other operations or components. The conditions of the well, *e.g.*, well bore temperature and environmental factors, must also be considered when choosing a degradable material. Generally, smaller molecule degradable materials are suitable for use in lower temperature application and larger molecule degradable materials are suitable for use in higher-temperature applications. It is within the ability of one skilled in the art, with the benefit of this disclosure, to select a suitable degradable material.

[026] The resin slurry of the present invention may be simply placed in a well bore or may be placed in a well bore at a pressure sufficient to create and fill one or more fractures along the isolated interval. Once the resin slurry is placed into its desired location, it is activated. Activation of the resin may be initiated, *inter alia*, by the use of a gas generating charge that is comprised mainly of a slow burning and nondetonating propellant; such charges are well known in the art. In some embodiments of the present invention, the propellant may comprise a modified nitrocellulose or nitroamine or a composite such as a composite containing ammonium perchlorate and a rubberized binder. Any conventional ignition device such as an electrical igniter, a pressure actuated detonator, or any other suitable device may be used to ignite the charge. As the combustion of the charge progresses after ignition, the combustion gas catalyzes the acid curable resin as a result of the acid by-products, such as gaseous hydrogen chloride, that are produced during the combustion of the charge. The acidic by-product may result from the combustion process itself, as when perchlorates are used, or may be produced by the reaction of additional constituents admixed with the charge that activate during the combustion process, such as would result from heat degradation of an acid ester.

[027] Some embodiments of the present invention, provide methods of creating permeable masses comprising the steps of isolating an interval along a well bore to create an isolated interval; placing a resin slurry comprising an acid curable resin, filler, and degradable material into that isolated interval; and then activating the acid curable resin using an activator. Activating the acid curable resin causes the acid curable resin to

substantially cure, causes the degradable material to substantially degrade, and thus forms a substantially stable, permeable mass.

[028] Other embodiments of the present invention provide methods of controlling sand in a subterranean formation comprising the steps of isolating an interval along a well bore to create an isolated interval; placing a resin slurry comprising an acid curable resin, filler, and degradable material into that isolated interval; and then activating the acid curable resin using an activator. Activating the acid curable resin causes the acid curable resin to substantially cure, causes the degradable material to substantially degrade, and thus forms a permeable mass capable of controlling the migration of particulates.

[029] The ignition causes the resin to set and the degradable material to degrade and leave behind a series of interconnected channels capable of conducting fluids through the otherwise solid mass of resin and filler. Following ignition and once the resin has become substantially solid and the degradable material has substantially degraded, the substantially solid mass of resin and filler left behind in the well bore may be drilled or reamed out to return the well to production. Where the resin slurry composition of the present invention is used for sand control, an annulus of the mass of resin and filler may be left between the walls of the formation along the well bore and the interior opening of the well bore.

[030] Therefore, the present invention is well adapted to carry out the objects and attain the ends and advantages mentioned as well as those that are inherent therein. While numerous changes may be made by those skilled in the art, such changes are encompassed within the spirit and scope of this invention as defined by the appended claims.